Chapter 4 - Fluids Requirements Envelope

4. FLUIDS REQUIREMENTS ENVELOPE

4.1 INTRODUCTION

The purpose of this section is to present a description of the fluids science requirements envelope. This is a top-level description in keeping with the intent of this document; more detailed discussions on the requirements are provided in supporting documents such as the individual Science Requirements Documents and hardware capabilities documents. The level of detail is intended to provide "envelope" requirements for necessary capabilities of use to most (if not all) experiments. The "envelopes" are defined in terms of selected detailed requirements from the basis experiments described in Appendix A.

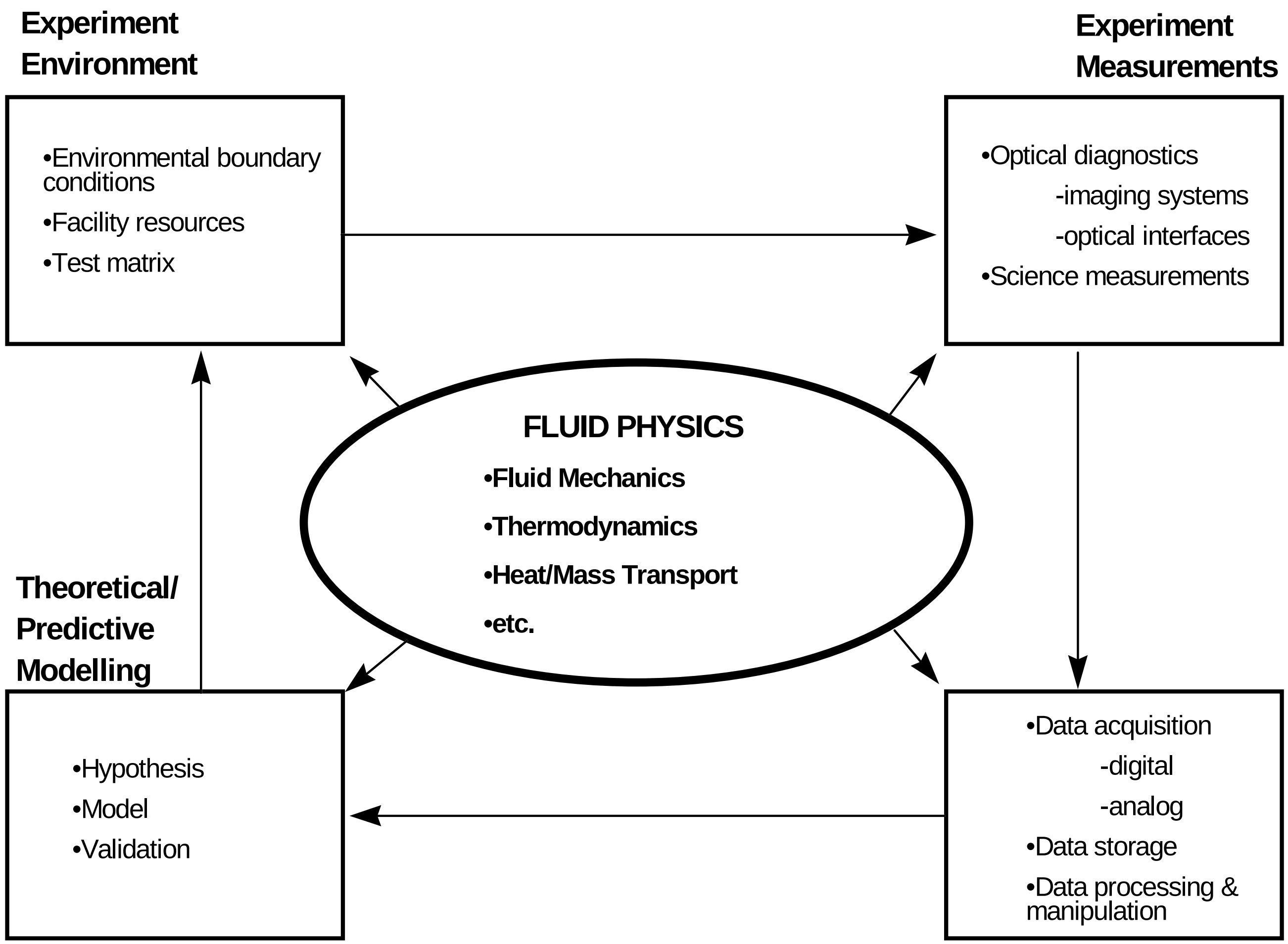
The discussion is organized as a logical progression of steps in the process of performing an experiment: The Principal Investigator (PI) proposes an hypothesis and supporting theoretical model of the phenomena to be investigated and defines the experiment(s) to be conducted in order to validate the hypothesis. Experiment definition involves establishing the experiment requirements, which include the experiment operating conditions and the experimental measurements to be made. The data obtained is analyzed and the results are compared with predictions of the theoretical model. The scope of this requirements discussion does not include theoretical modeling and data analysis but focuses on the experimental aspect of the process. Hence the following material is concerned primarily with experiment operating conditions and experimental measurements.

This section is divided into the following subsections:

- **Experiment Environment (Section 4.2):** These requirements define the physical conditions under which the experiments are conducted. The requirements emphasize the environment external to the actual fluid sample. These include environmental (boundary) conditions (accessible working volume(s), acceleration, temperature, etc.), resource requirements (power, light sources, cooling, stowage, etc.), and test times and frequencies.
- **Experiment Measurements (Section 4.3):** These requirements define the measurement capabilities and parameters to be measured and typically apply to phenomena occurring within the fluid sample. These include descriptions of required optical diagnostic systems and scientific measurements.
- **Data Management (Section 4.4):** These are requirements on selected data acquisition and management capabilities. These include data acquisition and control, data storage, and time tagging of data streams.

Facing figure shows a logical evolution of the experimental process which has been used to organize the requirements which follow.

Experiment Process Model



4.2 EXPERIMENT ENVIRONMENT

The requirements discussed in this section pertain to selected generic support systems and to conditions under which experiments are to be conducted. This includes most of the physical bounds necessarily imposed by the facility, the operating environment, the scope of support services, and adequate operations time to accommodate each experiment.

The following parameters are presented below in terms of requirement envelopes which are generated in terms of the basis experiments included in this document.

- **Physical Environment (4.2.1):** The facility must provide generic capabilities to accommodate the mechanical installation of each experiment and the thermal and acceleration environment.
- **Facility Resources (4.2.2):** The facility must provide a basic set of resources including power, cooling, vacuum, communications, etc. to support experiment operations.
- **Test Time and Duration (4.2.3):** The facility must provide adequate volume, power and environmental control to accommodate experiment operations.

The following is a list of the requirements in this section that relate to the Experiment Environment:

Section 4.2.1 - Physical Environment:

Req. F1 Dedicated Volume For Science
Req. F2 Safety Containment
Req. F3 Experiment Test Cells
Req. F4 Acceleration/Vibration Environment
Req. F5 Environmental Temperature
Req. F6 Air Flow
Req. F7 Cleanliness

Section 4.2.2 - Resources:

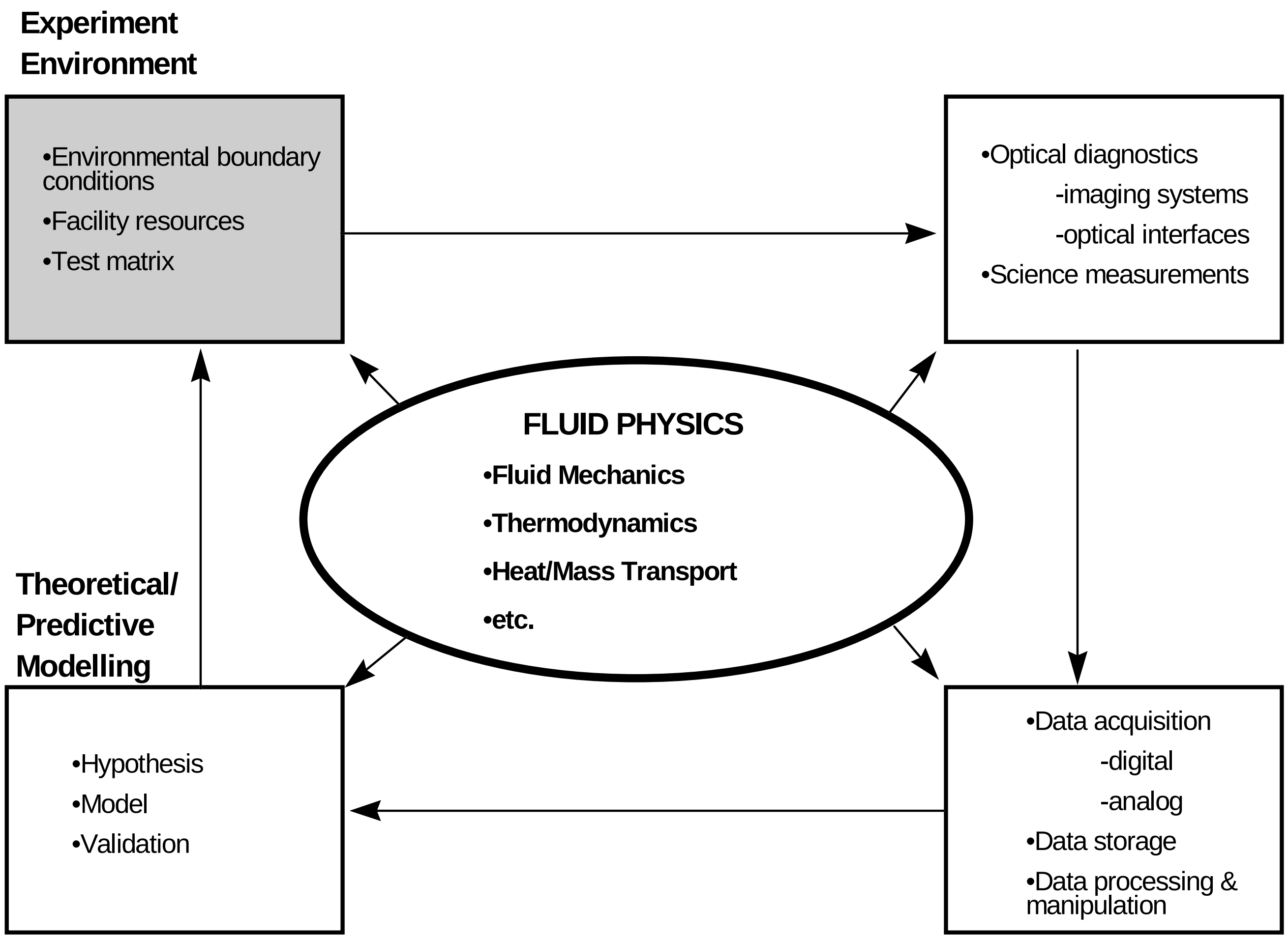
Req. F8 Power
Req. F9 Background Lighting
Req. F10 Laser Light Illumination
Req. F11 Vacuum
Req. F12 Cooling
Req. F13 Stowage

Section 4.2.3 - Test Time and Duration:

Req. F14 Number of Tests/Test Durations

Facing figure illustrates the experimental process previously shown with the Experiment Environment (this Section 4.2) highlighted. All requirements related to this environment are in this section.

Experiment Process Model



4.2 - EXPERIMENT ENVIRONMENT (cont.)

4.2.1 Physical Environment

Req. F1 - Dedicated Volume for Science

The facility shall:

- provide a large, dedicated science volume (may include facility cameras) that will accommodate experiment hardware typical of the basis experiments
- provide reliable and verifiable mounting locations within the science volume for experiment-specific and facility provided hardware
- be able to concurrently accommodate at least 2 experiments locations within the science volume, with distinct optical zones when appropriate.
- provide a rigid interface for movable experiment systems that shall not deform by more than 1.0 mm in any direction from its nominal dimensions

Des. DF1

In order to fulfill the goals for flexible utilization, it is essential that the facility provide a working volume that will not constrain future experiments to arbitrarily small packages. This working volume will be as large as possible (33 x 43 x 9 to 13 inches (84 x 109 x 23 to 33 cm (w x h x d))).

Des. DF2

Accommodate the experiment-specific hardware (e.g., fluid sample cells, custom power supplies, amplifiers, chillers, dedicated computers, and diagnostics, etc.)

Dick:

1) Overall, the facility should strive to make the evolving PI specific cameras available to other investigators when needed.

2) Fluid Dynamics can be removed from the process model diagrams.

3) Data recording section... need to refer to Combustion requirements (No.21.?)

4.2.1 Physical Environment (cont.)

Req. F2 - Safety Containment

The facility shall be capable of providing at least one level of containment for light, laser radiation, contamination (dust), and frangibles. The facility shall provide a temporary level of containment for fluids during experiment reconfiguration and test cell change-out. It is expected that this temporary containment will provide a glove-box like function in conjunction with the facility resources.

It is recognized that this expectation maybe an engineering challenge to the facility; but pushing all containment barriers onto experiment specific systems will require repetitive engineering of such systems and limit facility options for containing and recovering from potential spills or leaks.

The facility shall provide containment at the level of the largest practical volume (e.g., by providing large research module units that address containment, optical and other interfaces, and transportation and integration concerns). This would enable the greatest flexibility in experiment implementation and provide the least impact on experiment-specific sample systems.

The facility shall provide a fire detection and suppression system in the science volume, and a system for recovery from suspected contamination.

Des. DF3

It is desirable for the Fluids Facility to provide capabilities for gas sampling and atmosphere circulation within the science volume that are compatible with analysis and filtration systems in the Combustion Facility. This would enable recovery from suspected contamination.

4.2.1 Physical Environment (cont.)

Req. F3 - Experiment Test Cells

The facility shall accommodate baseline FOV’s up to 10 x 10 cm (Cf. Req. F19, 20), and preferably as large as 30 x 40 cm. The fields of view may or may nor encompass the entire test cell area.

The facility shall accommodate test cells sizes at least 15 x 17 x 19 inches (38 x 43 x 48 cm (w x h x d)), and consider adaptability of such a size with mid-deck locker size, express rack size, and other transport racks sizes. These dimension shall be consistent with the research module (Cf. Req. F2) that would provide one level of containment. Test cells in excess of the above mentioned baseline size shall be accommodated with reductions in facility-provided imaging capabilities allowable.

The facility shall accommodate PI-specific hardware packages up to 33 x 43 x 9 to 13 inches (84 x 109 x 23 to 33 cm (w x h x d)) when facility-provided imaging and illumination services are not required (Cf. DF1).

Experiment-specific hardware that directly contains the fluid samples is, herein, designated as a "test cell". Note that the total volume of the PI-specific hardware (including the test cell) may be larger than indicated in Appendix E when such experiment-specific sub-system volumes are also considered.

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4.2.1 Physical Environment (cont.)

Req. F4 - Acceleration and Vibration Environment

The facility shall be capable of providing an operating environment (at the test sample) that accommodates the envelope of limiting accelerations identified for the basis experiments or SSP 41000 (whichever requirement is less demanding). (Note: It is believed that all basis experiments can be accommodated within the limits defined in specification SSP 41000.)

This is essential because the quality of the acceleration environment is a significant concern for all microgravity experiments. It is expected that the facility will assure that appropriate environments are available to meet each experiment's requirements. Detailed requirements are not clearly defined for all basis experiments. Presumed limits for quasi-steady state accelerations are defined for most experiments and those limits fall within the range 10^{-6} to 10^{-2} g/g_0. Constraints on vibratory and impulse excitations are not defined explicitly for the basis experiments but are believed to be consistent with the NASA Code UG specification (SSP 41000). Selected examples of analytical predictions of vibratory sensitivity are shown in a subsequent figure relative to the SSP 41000 criteria.

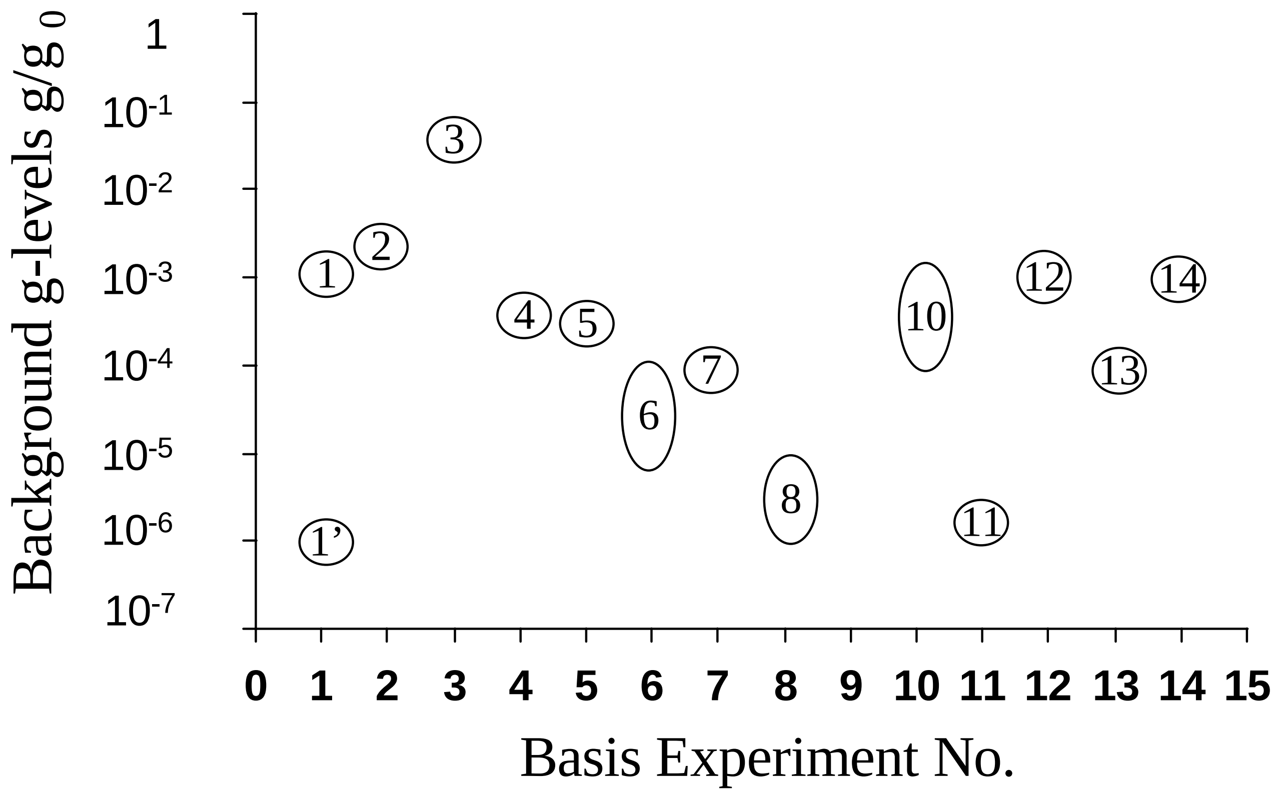
The facility shall accommodate an accelerations measurement device as close as possible to the test cell.

These measurements shall be in 3 orthogonal directions, from to 10^{-2} g to 10^{-6} g, from DC to 300 Hz. The accuracy shall be at least +/- 10% in the full range. These data shall be available in various formats (g-levels vs. time, g-levels vs. Frequency), and as post-mission data and in near real time.

Note: In the following 2 figures, experiment numbers 1 and 1' correspond to with and without g-vector alignment, respectively.

Facing figure displays envelope of acceleration required by selected basis experiments.

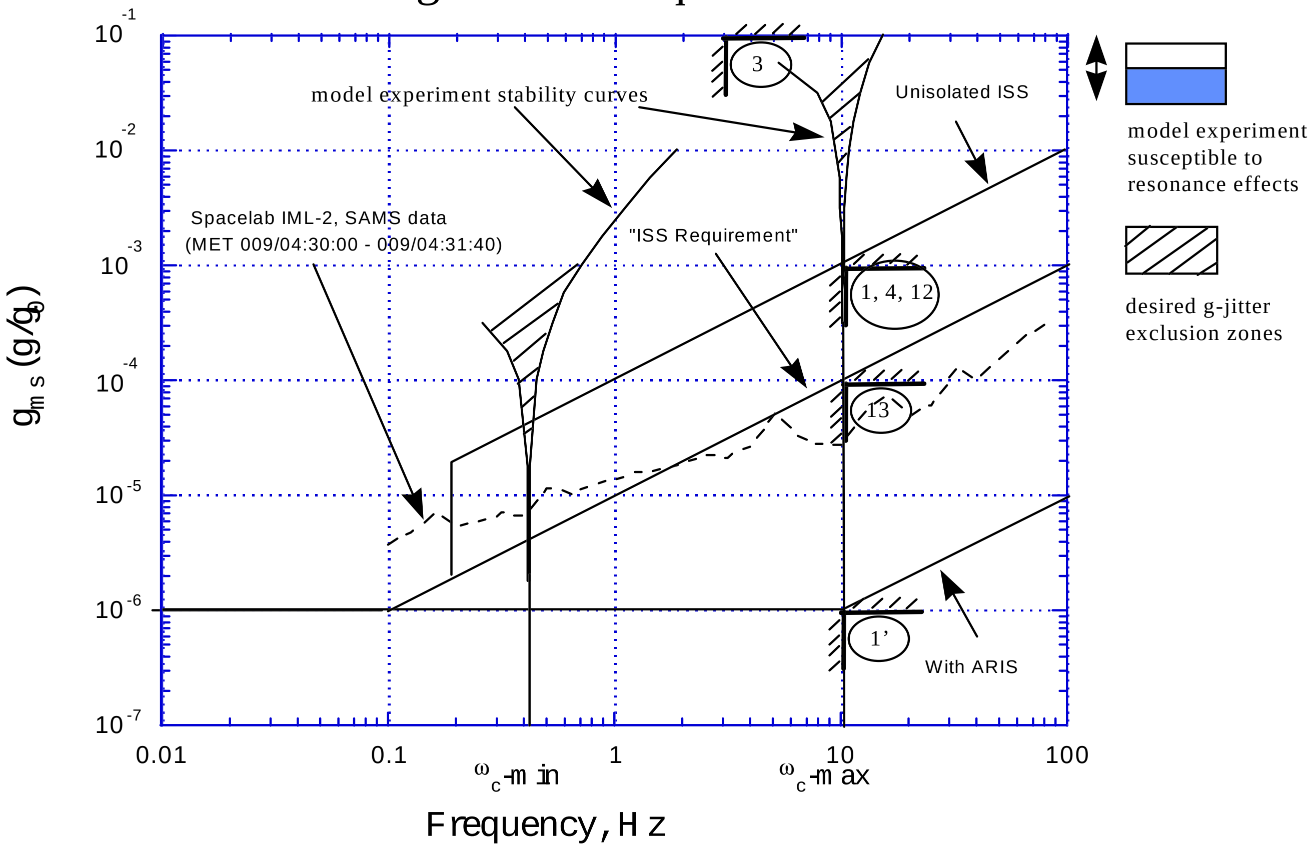
Background g-Levels Needed For the Basis Experiments



Req. F4 - Acceleration and Vibration Environment (cont.)

Facing figure highlights analytical estimates of resonant vibrations characteristic of particular sample geometry

Spacelab, and Space Station Environments, and g-Gitter Requirements



4.2.1 Physical Environment (cont.)

Req. F5 - Environmental Temperature

The facility shall provide nominal operating temperature range similar to Earth-based laboratories (22 - 29 °C).

The facility shall provide this temperature controlled environment, stabilized to ±1 K°, during experiment operations, for all experiment power levels up to 300W, irrespective of the ISS constraints.

To provide an appropriately stable operating environment for precision measurements (particularly for optical systems), it is necessary that the local temperatures be controllable and, in some situations, selectable. Precision temperature control is presumed to be applied at the sample and implemented with experiment-specific capabilities. A stable environment will enable the precise science requirements to be accomplished.

It should be noted (see Appendix E) that, while operating in this controlled environment, sample temperatures will be independently controlled to experiment-specific precision over a large range (-20 to +100°C for the basis experiments).

Des. DF4

It is desired that the facility measure the relative humidity, accurate to within +/- 10%, in the science volume.

4.2.1 Physical Environment (cont.)

Req. F6 - Air Flow

The facility shall provide for two scenarios regarding air flow.

1) The facility shall provide a stable atmosphere for science operations such that the flow of air around measurement systems in the science volume can be controlled.

Under the above conditions, there would be reduced thermal fluctuations for optically sensitive experiments, and enhanced optical cleanliness (Cf. Req. F7).

Precise optical and thermal measurements can be affected by density gradients in the transmitting medium and by fluctuations in thermal and density fields due to moving air during periods of measurement. For the most precise measurement requirements, it will be necessary to control the movement of air in the vicinity of the sample and optical systems.

2) The facility shall provide a stable atmosphere for science operations such that air circulation around measurement systems in the science volume can be achieved (say, by providing a stirrer fan).

Under this above condition, thermal management in the science volume would become easier by the imposed forced convection, facilitating simpler PI specific hardware design, and easier use of flight-proven COTS hardware.

4.2.1 Physical Environment (cont.)

Req. F7 - Cleanliness

The facility shall provide physical and procedural controls to limit levels of contamination on all optical systems during handling, operation, and storage. The facility shall provide capability to provide management of the contamination level in the science volume sufficient to meet imaging, illumination, and laser light quality requirements. It is recommended that optical element transmission be maintained >60% of day 1 transmission.

The primary measurement tools for many experiments involve optical systems and components that can be degraded by surface contamination. Sources of contamination are manifold (e.g., handling (even with nominal controls), air-borne particles (Cf. Req. F6), condensable vapors, and creep of local lubricants and solvents). The more desirable concepts for implementing optical diagnostic systems involve manipulation of unprotected optical elements and, therefore, every experiment will be susceptible to the effects of such contamination.

Of particular concern are "facility optics" which may remain on-orbit for extended times and be used as part of many experiments. The degradation in performance due to cumulative contamination could prohibit acceptable levels of transmission and scattering and is a serious concern to each user.

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4.2.2 Resources

Req. F8 - Power

The facility shall provide conditioned power for science operations of up to 400 W (typical) and up to 1000 W on a case by case basis. It is expected that several power circuits will be required for PI specific equipment. This will be especially important for the multiple experiments scenario. Voltages shall be supplied at levels which are typical of avionics-COTS hardware (in the 5 to 28 V range).

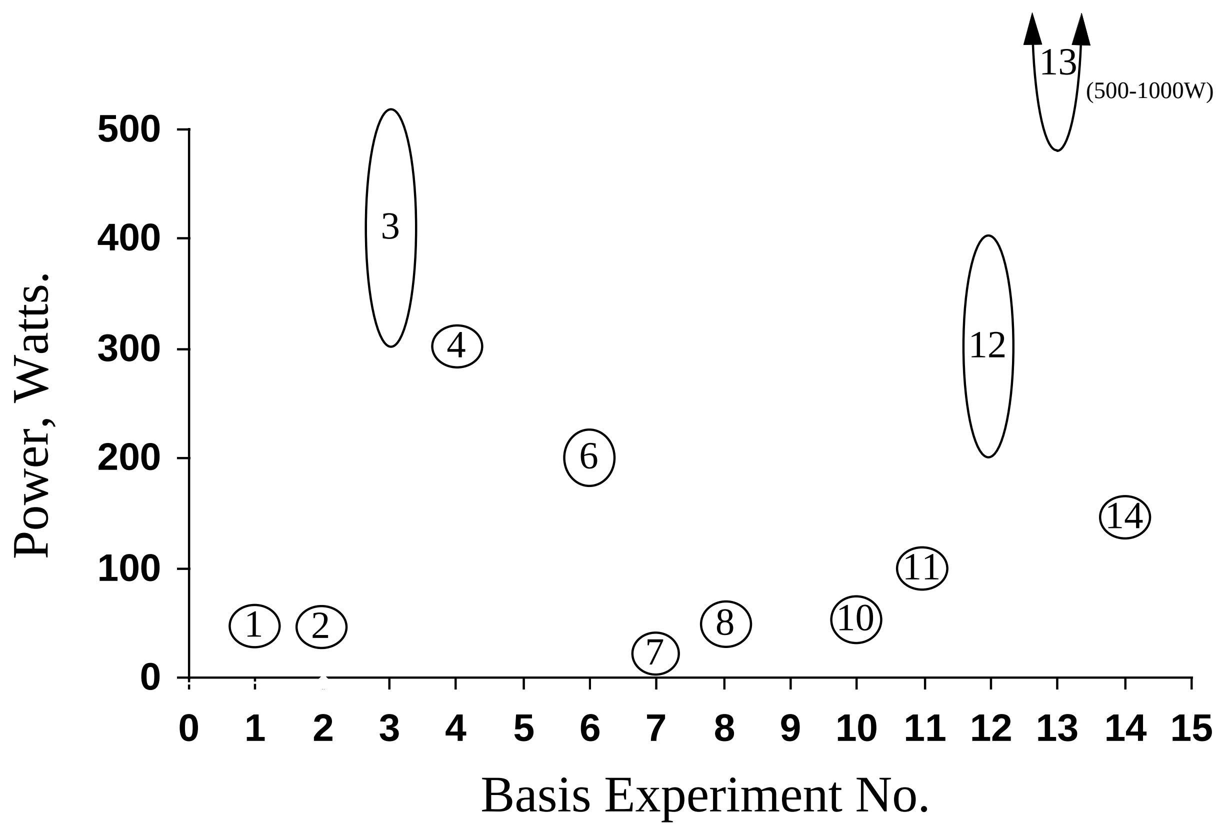
The broad scope of fluids experiments includes a wide range of instrumentation and controls and, therein, a wide range of power demands. The accompanying figure gives estimates of the power required for the basis experiments.

Des. DF5

It is desirable to implement experiment components, and experiment-specific cards to individually receive power or implement a "sleep" mode on such cards to selectively conserve power resources during low levels of use.

The facing figure show the range of power required by the basis experiments.

Power Requirements For the Basis Experiments



4.2.2 Resources (cont.)

Req. F9 - Background Lighting

The facility shall provide broad band lighting at the test cell with the following requirements:

- Illumination shall be provided over the baseline 10 x 10 cm field of view, with a capability to expand the background lighting up to 30 x 30 cm.
- Sufficient intensity shall be provided for proper exposure to meet image quality requirements (it is expected that the intensities required would range from 0.01 to 10 mW/cm^2 (typically 1 mW/cm^2)).
- Uniformity shall be consistent with resolution requirements (Cf. Req. F18). The maximum gradient in the illumination field (noise) shall be at least four times smaller than the gradient of any significant edge* in the image. The variation in back light intensity shall not exceed ± 10% when comparing any 4 x 4 mm area with overall mean intensity.

*The background lighting and camera combination shall be capable of discerning edges that might exhibit as few as 10 gray scale units per pixel.

Des. DF6

It is desired that the illumination not limit the optical resolution and not cause ringing in the image (i.e., the light must only be partially coherent).

4.2.2 Resources (cont.)

Req. F10 - Laser Light Illumination

The facility shall provide laser illumination over the range of wavelength and power required by the basis experiments.

The facility shall identify the initial complement of lasers to accommodate a balance of initial experiment-specific requirements and long-range utility. It is important that the facility architecture allows for laser upgrades to maintain the state-of-the-art capability.

Laser light is employed in many optical measurement systems. Laser light illumination can take a variety of forms (e.g., laser light sheets, collimated beams, and point illumination of the sample).

The facility shall be capable of generating light sheets with the following characteristics:

- width to 5 cm (with potential extension to 10 cm when required by specific requirements).
- sheet thickness 100 to 1000 µm
- divergence of the sheet shall be minimized as much as possible (up to optical diffraction limits)
- translation ±5 cm with resolution of ± 0.1 mm.

Precision light sheets are used to illuminate selected planes within test cells when performing particle image velocimetry.

The facility shall provide collimated beams of at least 5 cm diameter, and a capability to expand the beam up to 10 cm.

Des. DF7

It is desired that the facility be capable of maintaining at least 4 lasers on orbit and have additional laser heads available for modifications and change-out. It is presumed that solid state lasers will be used whenever possible.

Des. DF8

It is desired that laser heads be considered distinct and detachable from drivers for flexibility.

A recommended set of lasers for initial consideration is indicated in the following table:

Source	Wavelength	Laser Power at Cell	
Nd:YAG	532 nm	35 mW	(up to 100 mW)
Nd:YAG	532 nm	10 mW	(pulsed at 30 Hz)
Diode	770 nm	50 mW	(up to 100 mW)
Diode	670 nm	50 mW	
HeNe	632 nm	5 mW	
HeNe	632 nm	35 mW	

4.2.2 Resources (cont.)

Req. F11 - Vacuum

The facility shall provide access to the vacuum vent system for each experiment requiring this capability. This vacuum capability shall be similar to the standard laboratory capabilities (or be the maximum allowed by the ISS) in terms of mass flow rates, and vacuum levels. (It is primarily intended to use this capability to create lower than ambient pressures required within some experiment test cells, for liquids/bubbles suction/collection capabilities, or for some pneumatic operations.)

4.2.2 Resources (cont.)

Req. F12 - Cooling

The facility will be useful only if the thermal environment (Cf. Req. F5) can be stabilized by removal of dissipated heat.

The facility shall provide cooling commensurate with power dissipation of facility hardware and required experiment-specific equipment needs.

Des. DF9

The facility must strive to size the cooling systems to permit future growth in capabilities and usage.

Des. DF10

The facility cooling concepts must be consistent with the need to minimize temperature gradients (Cf. Req. F6) and variations which could degrade performance of optical systems.

4.2.2 Resources (cont.)

Req. F13- Stowage

It is estimated that approximately 80 liters of stowage will be needed.

The facility shall provide stowage to accommodate:

- Active experiment-specific supplies (e.g., samples, ..)
- Queued experiment-specific hardware and supplies

It expected that some of the above stowage might require a moderate power supply (e.g., standard powered-stowage-racks provided by the ISS). This capability is to maintain some fluid samples stirred, to maintain thermal control (including refrigeration), etc. (during the ground ops, launch & descent, on-orbit pre & post experiment periods)

The facility shall also provide stowage to accommodate:

- facility on-orbit equipment (e.g., cameras, laser heads, optics, cleaning/bagging materials, gloves, windows)
- facility spares commensurate with reliability goals (e.g., selected electronics, cables)

Because of the well known shortage of on-orbit stowage, it is necessary that the facility demonstrate a careful plan to account for and fully utilize all available stowage.

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4.2.3 Test Time and Test Duration

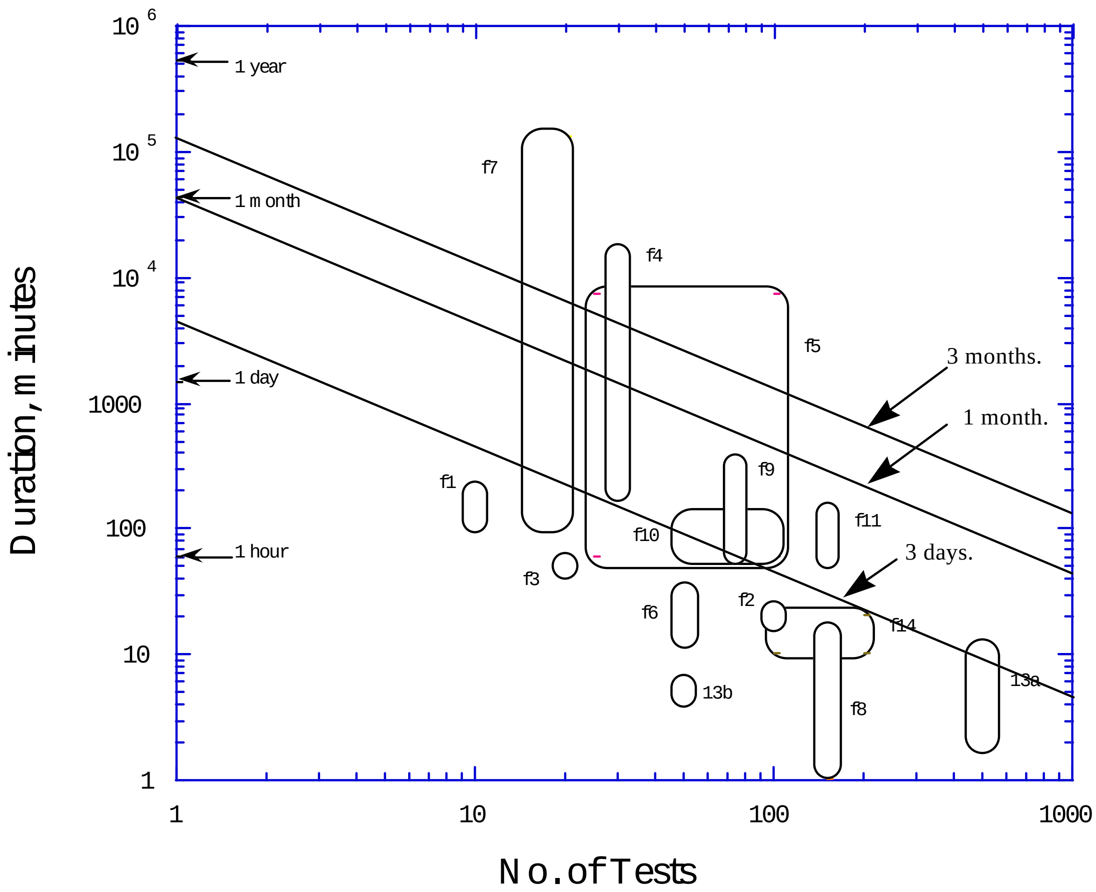
Req. F14 - Number of Tests/ Test Durations

The Fluids Facility shall accommodate experiments requiring number of tests in the range exhibited by the basis experiments. The basis experiments exhibit 10 to 500 test points of varying test duration. The actual number of test points, however, will be defined in the individual Science Requirements Document. Also, the basis experiments exhibit test durations nominally from ~1 minute to many days (potentially 30). The test duration reflects the length of one test run only. It does not include factors such as experiment setup times, and change-out requirements.

These data are plotted in the following figure. Also shown are total experiment duration lines (3 days, 1 month, and 3 months). However, the actual total experiment time will be larger for several reasons: warm-up times for experiments, availability of low-g levels, most profitable science teams working hours of 10-12 hour/day, and time for analyzing the data and replanning the next steps. Performing two simultaneous experiments will be served well under the above operational scenario (Cf. Req. F1).

The facing figure shows the ranges of test count and test duration exhibited by the basis experiments.

No. of Tests and Durations



4.3 EXPERIMENT MEASUREMENT CAPABILITIES

The requirements discussed in this section pertain to selected measurement tools and measurement ranges called out in the basis experiments.

The following parameters are presented below in terms of requirement envelopes which are defined by the basis experiments included in this document.

- **Imaging Capabilities (4.3.1):** The facility must provide the capabilities for basic imaging and photographic documentation of the experiments.
- **Optical Interfaces (4.3.2):** The facility must provide a precise and stable platform for implementing required optical measurement systems.
- **Optical Measurements (4.3.3):** The facility must provide measurement capabilities which accommodate the range of requirements called out in the basis experiments.
- **Analog Measurements (4.3.4):** The facility must provide necessary capabilities for making typical measurements of analog sensors (e.g., temperature, pressure, force, and voltage)

The following is a list of the requirements in this section that relate to Experiment Measurement Capabilities:

4.3.1 - Imaging Capabilities

Req. F15	Imaging Systems

4.3.2 - Optical Interfaces

Req. F16	Number of Views
Req. F17	Optical Indexing

4.3.3 - Optical Measurements

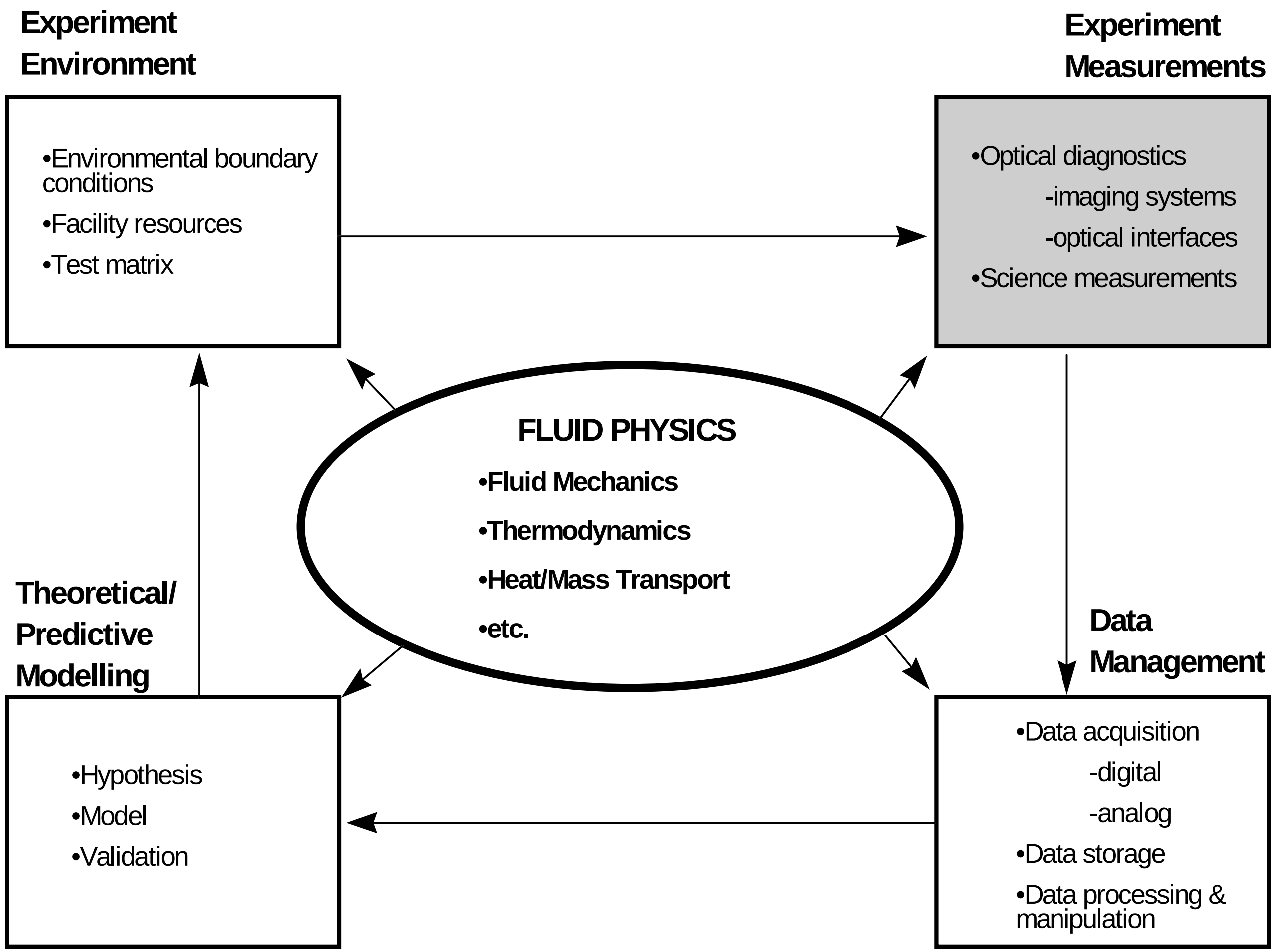
Req. F18	Field of View vs. Resolution
Req. F19	Particle Speed vs. Field of View
Req. F20	Frame Rate vs. Experiment Duration
Req. F21	AOS, LOS Requirements

4.3.4 - Analog Measurements

Req. F22	Analog Measurement

Facing figure illustrates the experimental process previously shown with the Experiment Measurements (this Section 4.3) highlighted. All requirements related to these measurements are in this section.

Experiment Process Model



4.3 EXPERIMENT MEASUREMENT CAPABILITIES cont.)

4.3.1 Imaging Capabilities

Req. F15 - Imaging Systems

Fluids experiments span a wavelength range from 14 μm to 400 nm. The facility shall provide a selection of relevant cameras covering the entire visible spectrum. Selected UV and IR regions will be accommodated with PI provided cameras. The facility and facility provided cameras shall have the following capabilities:

- standard camera features (e.g., focus, zoom, aperture, shutter speed) be remotely controllable.
- selected frames, or a sequence of frames be provided to ISS for downlink
- all necessary accommodations (e.g., power, data, mirrors, windows, etc.) for PI provided cameras
- a minimum of two cameras be operated at the same time
- time information, accurate to 0.001 sec., embedded in image files (Cf. Req. F26)
- facilitate quick connects of control, data, and power line cables for PI specific cameras.
- flexible camera placement.

Des. DF11

It is desirable that the facility have the following additional capabilities:

- accommodate use of both digital and analog cameras
- IR imaging to wavelengths of 14 μm
- anti-blooming features for all cameras
- detachable lenses and zoom capability with all types of cameras
- a provision for storage of unused and exposed films in a radiation protective environment.

The table on the facing page summarizes the types of cameras envisioned for the facility.

RANGE OF IMAGING SYSTEMS

Camera Types	UV	Visible/mono	Visible/color	IR
Analog video		PI	FCF	
Digital video	PI	FCF (2)	PI	PI
Cinematic		PI		
Digital stills		PI	PI	
Film-based stills		PI		

FCF = facility provided PI = PI specific

4.3.2 Optical Interfaces

Req. F16 - Number of Views

The facility shall accommodate simultaneous imaging of the test cell from at least two orthogonal directions.

The facility shall support different fields of view or frame rate requirements for each view.

There will be cases in which each view will require a different diagnostic (e.g., normal/zoom visual CCD, and interferometry), and there may be situations requiring two simultaneous but different imaging zones.

Data from two video channels (Cf. Req F15) should be provided in near-real time to ISS for downlink. The time delay for the near-real time videos shall not be more than 15 seconds. In addition, the facility shall provide a capability to downlink and view the images at selected frame number intervals (Cf. F15).

Des. DF12

It is desirable to have at least two viewing directions be accessible with zoom capability.

Des. DF13

It is desirable to have images of directly opposite views; e.g., front and rear view of an object should be accessible.

Des. DF14

It is desirable to have ability to image two orthogonal views side by side with the same camera.

4.3.2 Optical Interfaces (cont.)

Req. F17 - Optical Indexing

The facility shall provide a capability to reproducibly position light sources, imagers, test-cells, and other optical components to within ± 2.0 mm relative to an established reference.

Any item put into the facility by the crew on the optical bench(es) shall be coarse-aligned to specific reference points. The mechanism for such coarse-alignments shall be provided by the facility; (e.g., optical light beams that can be pointed at experiment specific components).

Des. DF15

It is desired that for precise-alignment purposes, optical rails, x-y-z positioners, x-z-θ positioners are provided on each of the optical surfaces. Positioning on the order of a few microns (or better when required by the Science Requirements Document) should be accessible.

4.3.3 Optical Measurements

The following three requirements deal with the field of view, resolution, frame rate, and duration of recording. These requirements result from considerations of diagnostic techniques such as particle imaging velocimetry (including the use of liquid crystals as particles), interferometry, and infrared imaging. These are used to map velocities, temperature and concentration profiles and fields.

Req. F18 - Field of View vs. Resolution

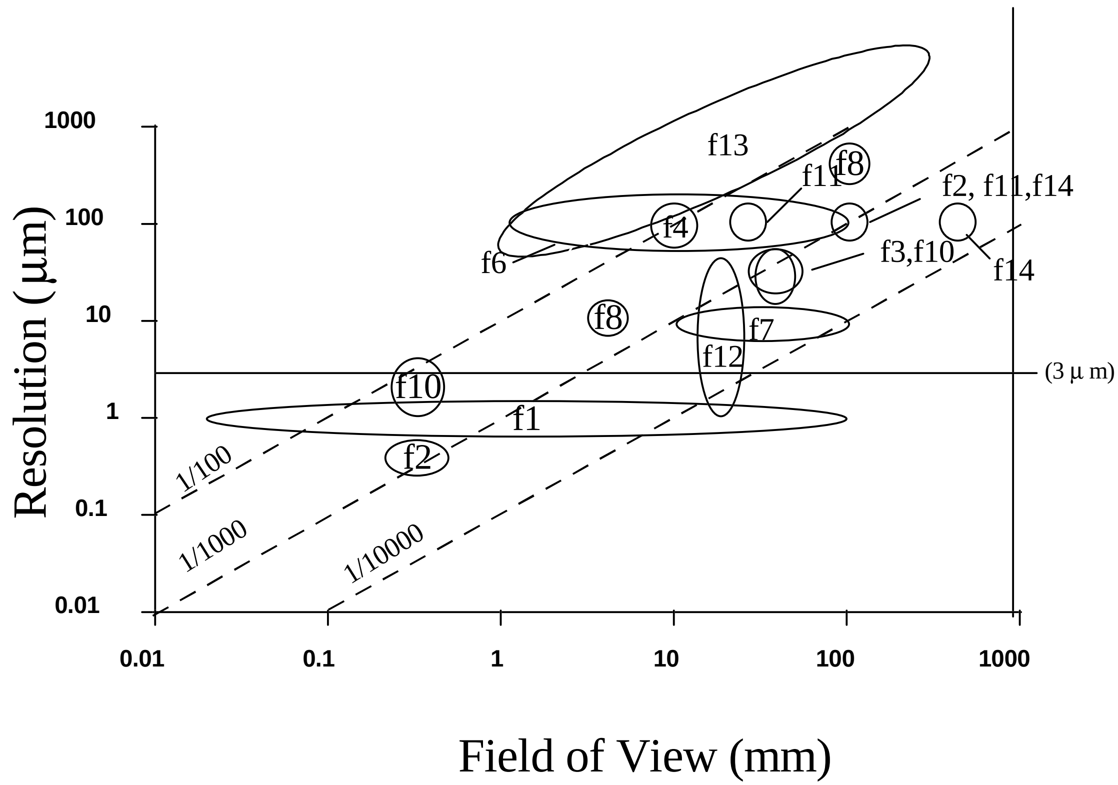
Basis experiments exhibit fields of view from 20 x 200 microns to 30 x 40 cm and resolutions from 0.5 to 1000 µm. The facility shall provide ranges of fields of view (FOV) and resolution as shown in the accompanying figure.

The facility shall support optical resolutions down to ~3µm, up to 1/1000 resolution to FOV ratio, and FOV up to 10 x 10 cm, and preferably as large as 30 x 40 cm.

Note on experiment f1, f2: Resolutions are below the optical limit. The desired resolutions would be achieved by interferometric or other diagnostic techniques.

The facing figure shows the distribution of image resolution and fields of view that define this requirement envelope. The graph shows that most of the data lies at a ratio of field of view to resolution of 1000 or less.

Field of View Versus Resolution



4.3.3 Optical Measurements (cont.)

Req. F19 - Particle Speed Versus Field of View

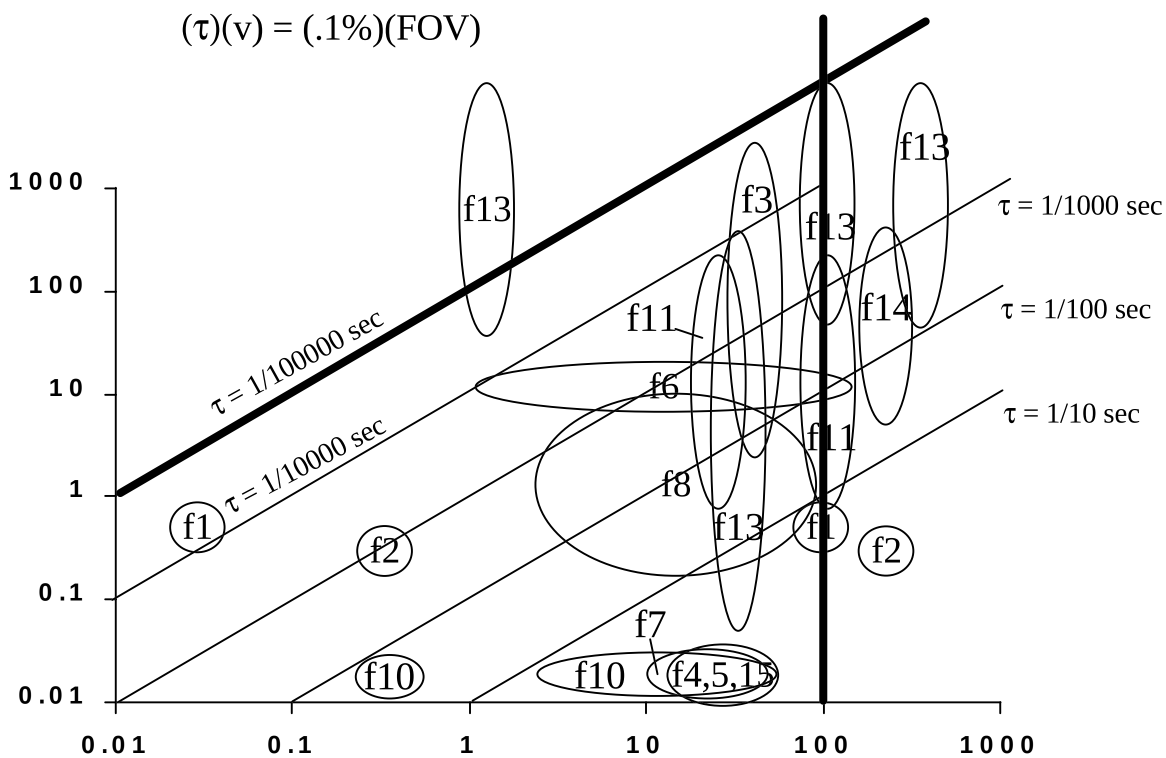
The facility shall accommodate the range of FOV's and expected particle speeds required by the basis experiments. Basis experiments exhibit fields of view between 20x200 microns to about 30x40 cm and particle speeds from 200 microns/sec to 10 m/sec.

To obtain sharp images, the facility shall provide effective exposure times to adequately freeze particles (or objects) in motion. The facility shall support FOV's up to 10 x 10 cm (and preferably as large as 30 x 40 cm) for exposure times down to 10 μs, as indicated in the following figure.

In the following figure, it is assumed that events can be frozen by allowing a maximum translation of 0.1% of field of view; then, the resulting exposure time, t, is in the 1/100 to 1/100,000 sec range.

The facing figure shows the distribution of particle speeds and fields of view that define this requirement envelope.

Exposure Time as a Function of Particle Speed



Field of View (mm)

4.3.3 Optical Measurements (cont.)

Req. F20 - Frame Rate Versus Experiment Duration

The facility shall provide the ranges of framing rate and image recording duration required by the basis experiments. Basis experiments exhibit frame rates from occasional to 1 fps to 1000 fps and recording duration from 5 to 2000 seconds per experiment run.

The facility shall accommodate frame rates up to 1000 fps.

The facility shall be able to store at least up to 10 Gb of data (thus be able to record 10 sec of 1024 x 1024 (10000 frames), or 40 seconds of 512 x 512 (40000 frames), b/w video at 1000 fps.)

The facility shall also provide a capability to variably select an area of interest (AOI) within the field of view for recording purposes (e.g., a 60 x 40 pixel array). It is expected that this capability could increase the duration of recording of smaller AOI's at the highest fps.

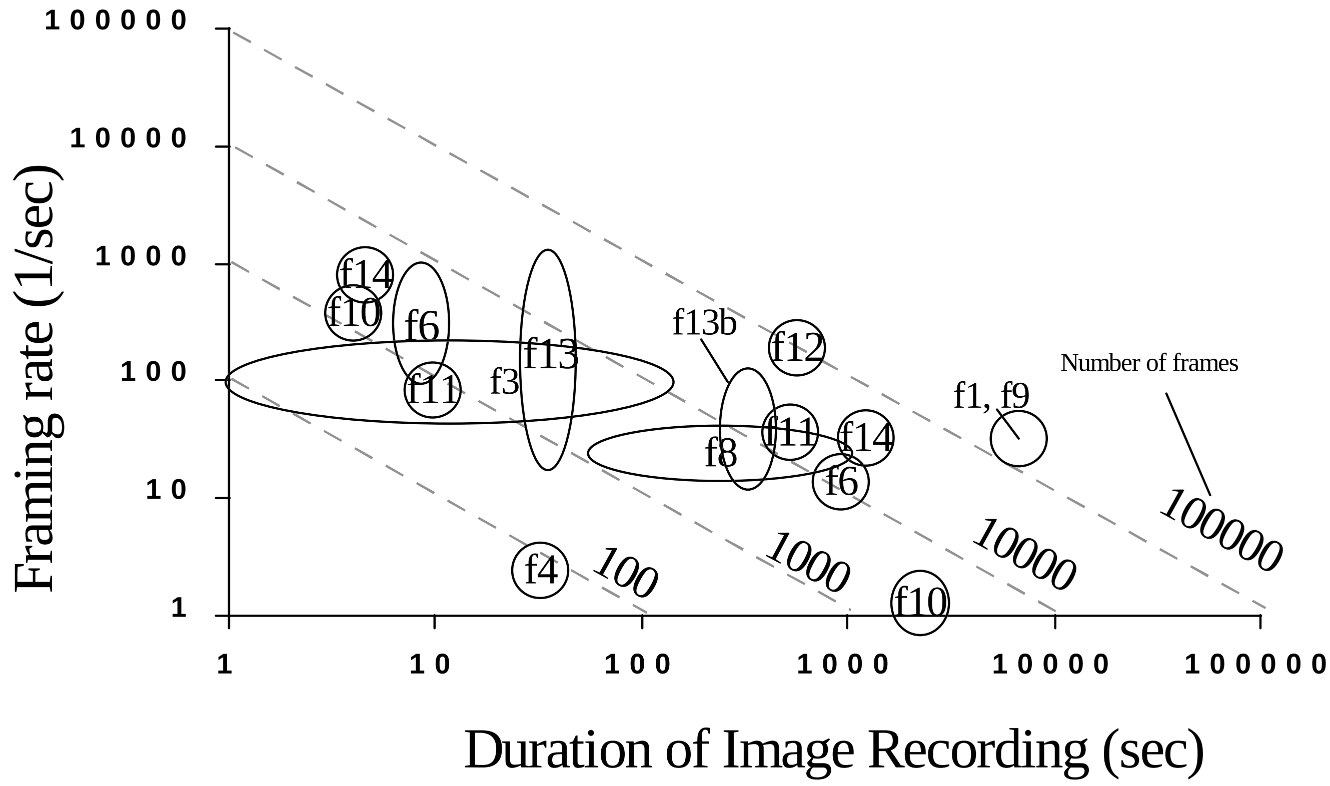
The following figure shows that generally higher frame rates are required for shorter duration, and that the estimated total number of frames is less than about 50,000 for any one experiment run. Also, in experiment f10, some cases will require 6 minutes between frames (time-lapse mode). In experiment f12, only a smaller subset (up to 20 seconds) of the 5 minutes at 200 fps would be of interest, and the point on the x-axis represents taking occasional pictures. In experiment f13, it is desirable to have up to 300 x 512 pixels at 1000 fps for 15 minutes.

Des. DF16

It is desired that the facility must not preclude higher camera frame rates (e.g., 2000 fps). The frame rate capability should increase as higher speed cameras and higher capacity storage devices become available.

The facing figure shows the distribution of frame rates and recording duration that define this requirement envelope.

Recording Duration For Various Framing Rates



4.3.3 Optical Measurements (cont.)

Req. F21 - AOS, LOS requirements

The facility shall provide at least one removable recording media device that is capable of recording up to 2 hours of standard video data.

Des. DF17

As much of continuous communication with the facility as possible is desirable.

At least 67% communications coverage is desired to send commands, and receive instrumentation and image data.

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4.3.3 Optical Measurements (cont.)

It is expected that the Fluids Facility will exhibit optical measurement capabilities comparable to the Earth-based laboratory diagnostics used by the Principal Investigators. The facility concept must accommodate a wide variety of measurement techniques typical of modern fluid physics. The adaptability and flexibility of the facility for accommodating multiple configurations of precision optical diagnostics will be prerequisite to meeting the utilization goals for the facility.

The facility shall provide a versatile architecture to be able to switch between the required baseline diagnostics, and be able to accommodate all other diagnostics by appropriate on-orbit modifications.

Identifying an optimal mix of on-orbit, facility-provided capabilities while maintaining adequate free volume to implement experiment-specific hardware for each new experiment will require exceptional engineering of instrumentation hardware and careful coordination of science requirements. It is recognized that the initial facility capabilities will reflect the techniques required by the first experiments which must be accommodated.

The facing table presents a list of modern optical diagnostic techniques which is recommended for consideration and the demand for these techniques reflected in the basis experiments. The current emphasis on quantitative imaging is apparent.

RECOMMENDED OPTICAL DIAGNOSTICS

DIAGNOSTIC TECHNIQUE	BASIS EXPERIMENT	RECOMMENDED BASELINE CAPABILITY	RECOMMENDED UPDATED CAPABILITY
General imaging	f1 to f14	multiple views, zoom capability, particle tracking, color and b&w, frame rates to 300 per sec	high frame rates (to 2000 per sec)
IR imaging	f11		as required
Video microscopy	f1, f2, f10	2 views	
Static and dynamic light scattering	f4, f7, f12	required	
Shadowgraph	f11	required	
Schlieren			as required
Color schlieren			as required
Particle image velocimetry	f1, f2, f6, f10, f11	required	
Laser induced fluorescence	f10		as required
Mach-Zehnder interferometry	f8, f9, f12		as required
Michelson interferometry	f1, f12		as required
Twyman-Green interferometry	f12		as required
Point diffraction interferometry	f8, f9		as required
Shearing interferometry	f1, f8 f9, f12	required	
Liquid crystal point diffraction interferometry	f8, f9		as required
Laser feedback interferometry	f1		as required
Surface profilometry	f11	required	
Ronchi (surface slopes measurement)	f11		as required
Laser Induced Photochemical Anemometry			as required

4.3.4 Analog Measurements

The following requirement pertains to the local measurements of temperature, pressure, force, torque, stresses, voltage, current, magnetic field, linear and angular positions, and translational and rotational speeds. Such measurements usually transform to measurement of voltages from the various transducers.

Req. F22 - Analog Measurements

The facility shall be capable of accommodating storage and handling of instrumentation data from a variety of transducers at various data rates. The sampling rates and storage capabilities are summarized in Section 4.4 in terms of data management.

The following figures in this section, show the range, rate, and accuracy required for the basis experiments.

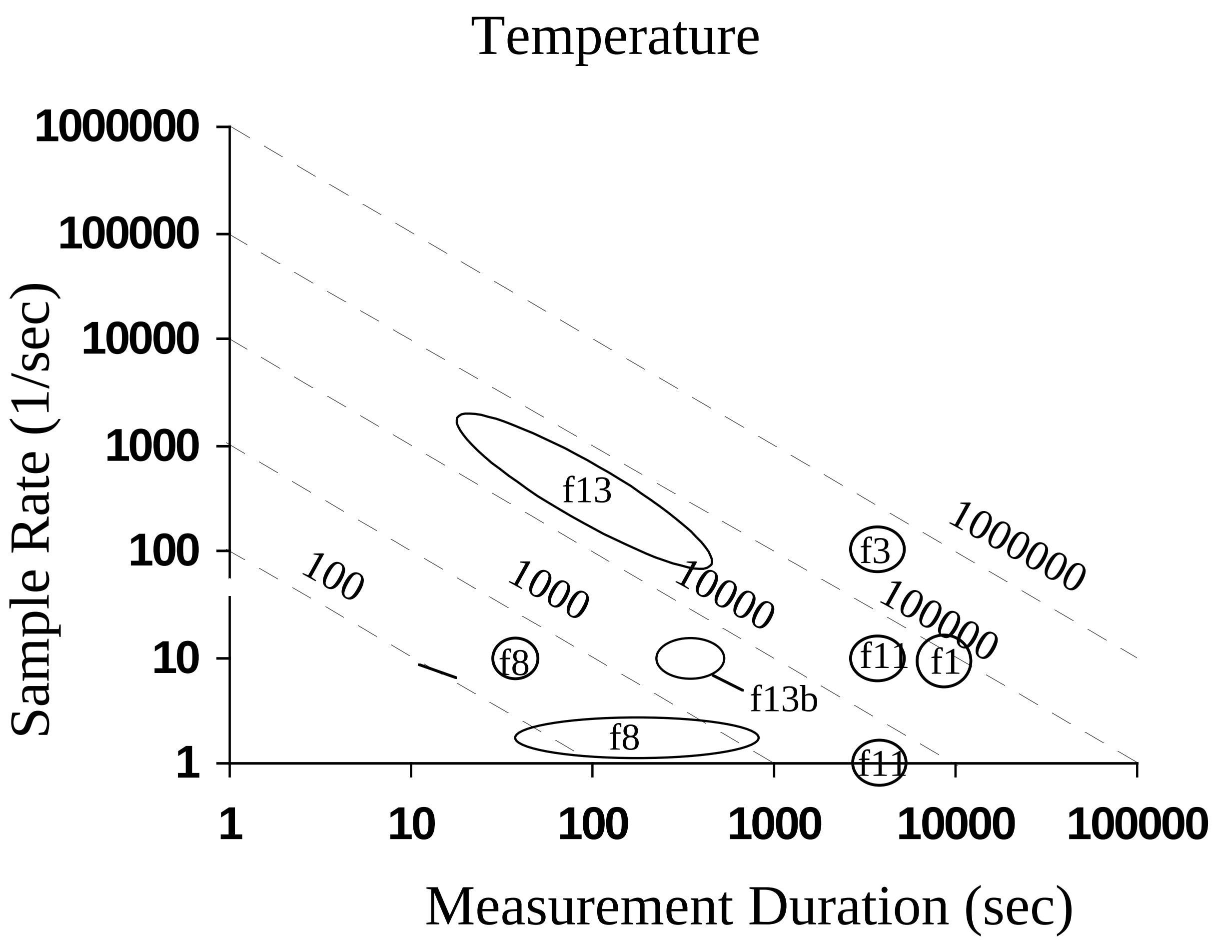
Temperature: Most of the temperatures expected range about ambient conditions. Experiments 8, 9, and 13 require temperatures ranging from about -20 to 120°C.

Pressure: These measurements, typically, need to be taken to within 0.1%; pressures for the multiphase flow experiments (13a, 13b) run from atmospheric to several hundred psia. Most other experiments are done at one atmosphere and measurements are nominal.

Force: For experiment #3, the force measurement ranges from 1 to 10,000 dynes at ±1 dyne, and 100 to 1,000,000 dynes at ±100 dynes.

Voltage: For experiment f6, the voltages range from 100 to 20,000 volts (AC and DC). These voltages are used to supply an electric field. The other voltages for experiments 12 and 13 are for resistance heaters.

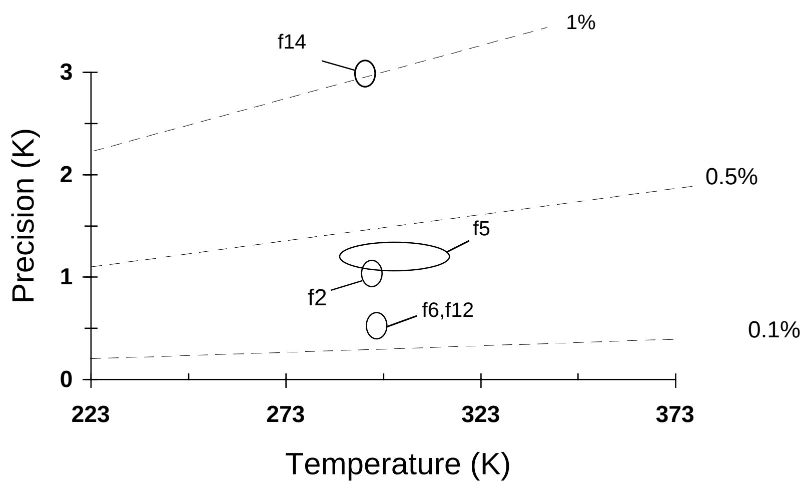
Facing figure shows ranges of temperature measurement rates and duration required by the basis experiments.


Temperature
Sample Rate (1/sec)
1000000
100000
10000
1000
100
10
1
Measurement Duration (sec)
1
10
100
1000
10000
100000
100
1000
10000
100000
1000000
f13
f3
f8
f13b
f8
f11
f1
f11

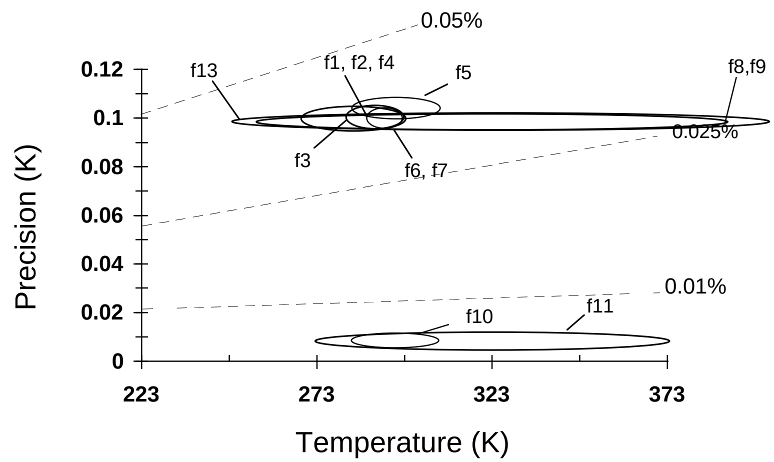
4.3.4 Analog Measurements (cont.)

Figures on facing page show the ranges of precision point temperature measurement called out by the basis experiments.

Point Temperature Measurement Precision 1/2



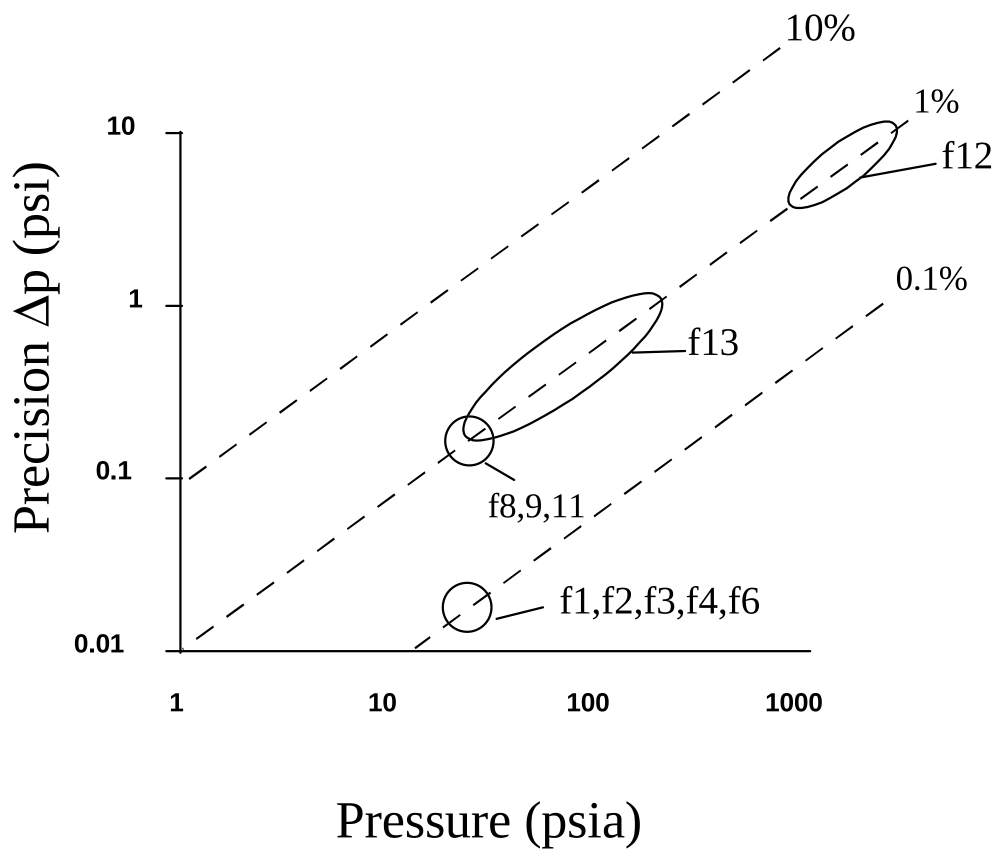
Point Temperature Measurement Precision 2/2



4.3.4 Analog Measurements (cont.)

Facing figure shows the ranges of sample rate, precision, and pressure measurement called out by the basis experiments.

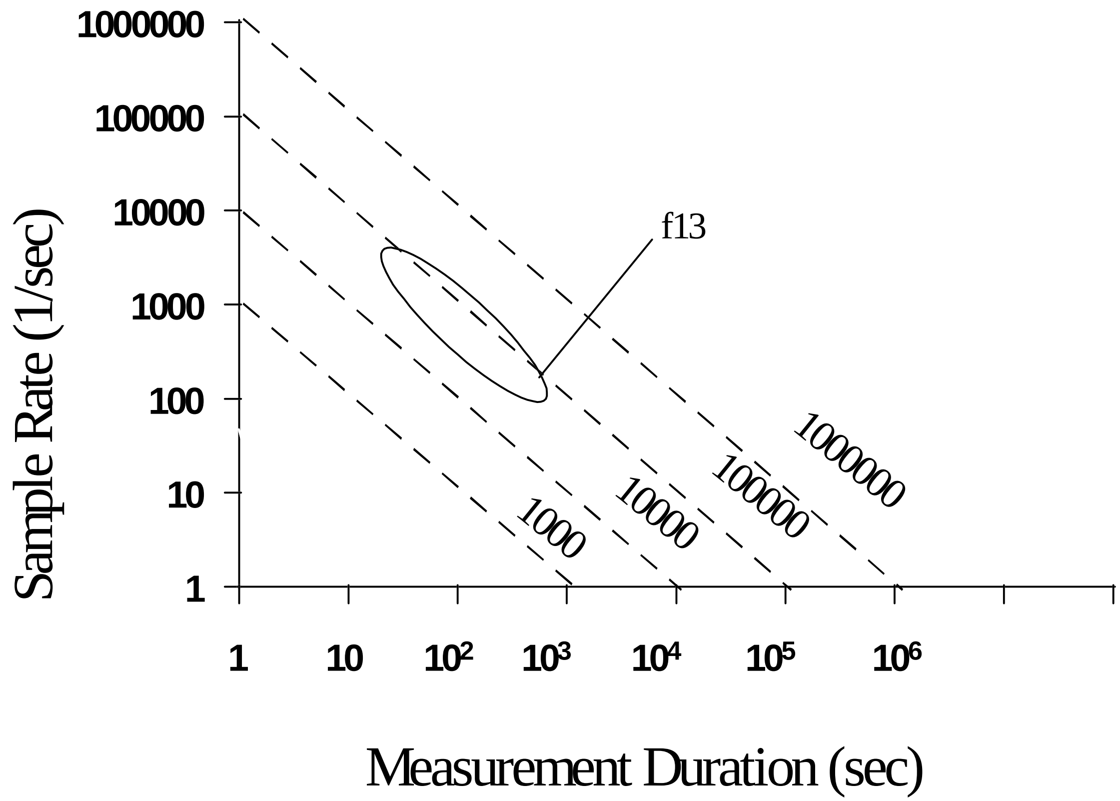
Pressure Measurement Precision



4.3.4 Analog Measurements (cont.)

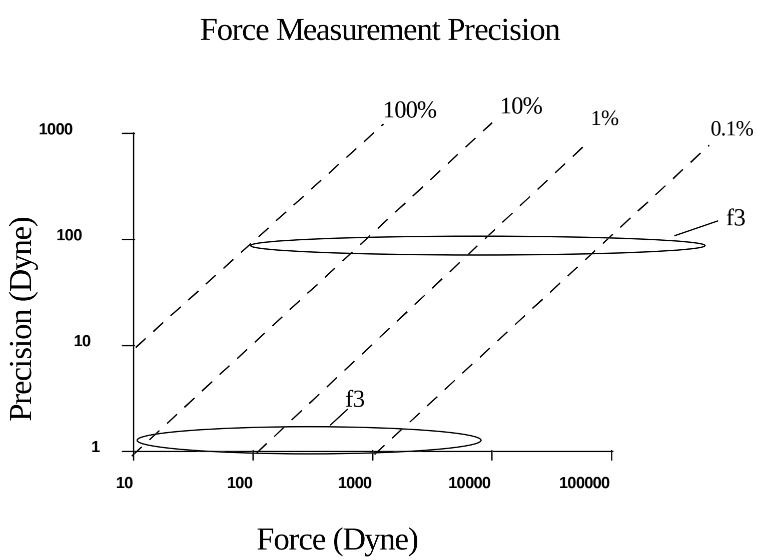
Facing figure shows the sample rate called out by basis experiment f13.

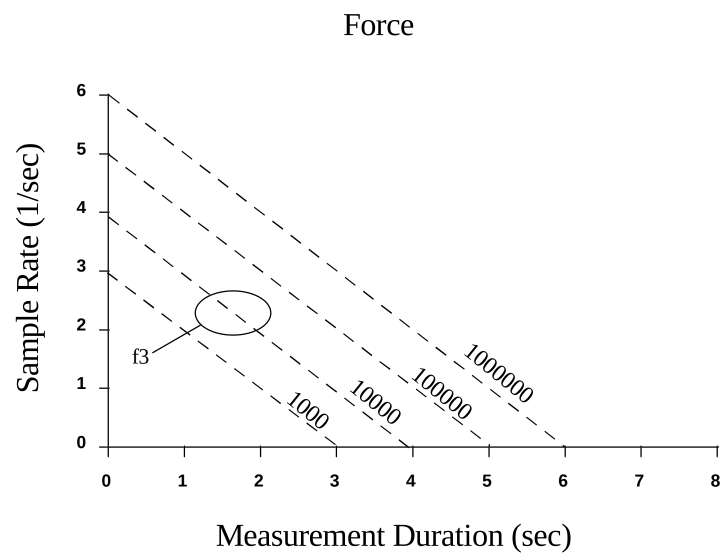
Pressure


Sample Rate (1/sec)
1000000
100000
10000
1000
100
10
1
f13
1000000
100000
10000
1000
1
10
10^2
10^3
10^4
10^5
10^6
Measurement Duration (sec)

4.3.4 Analog Measurements (cont.)

Facing figures show the ranges of sample rate, precision, and force measurements called out by the basis experiments.

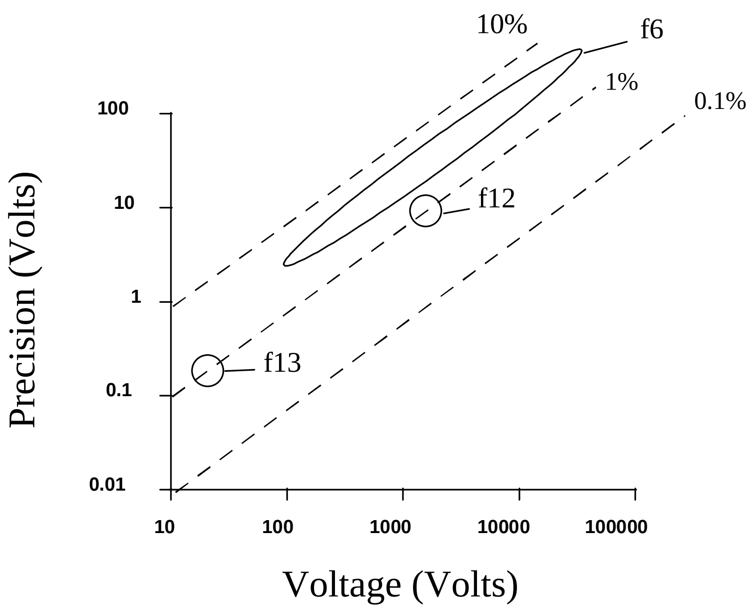

Force Measurement Precision
100%
10%
1%
0.1%
f3
f3
1000
100
10
1
Precision (Dyne)
10
100
1000
10000
100000
Force (Dyne)


Force
6
5
4
3
2
1
0
Sample Rate (1/sec)
f3
1000
10000
100000
1000000
0
1
2
3
4
5
6
7
8
Measurement Duration (sec)

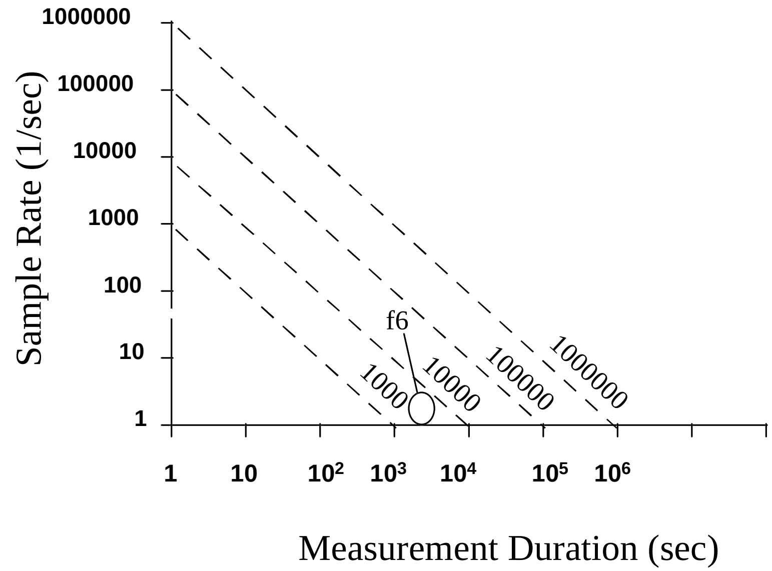
4.3.4 Analog Measurements (cont.)

Facing figures show the ranges of sample rate, precision, and voltage measurements called out by the basis experiments.

Voltage Measurement Precision



Voltage Sampling Rate vs. Experiment Duration



4.4 EXPERIMENT DATA MANAGEMENT

The requirements discussed in this section pertain to data system capabilities.

The following parameters are presented below in terms of requirement envelopes which are defined in terms of the basis experiments included in this document.

- **Data Acquisition (4.4.1):** The facility must be capable of acquiring both analog and digital signals.
- **Data Storage (4.4.2):** The facility must provide adequate data storage to accommodate data flow of the experiments.
- **Experiment Control (4.4.3):** The facility must be capable of controlling both digital and analog devices.

The following is a list of the requirements in this section that relate to Data Acquisition and Management:

4.4.1 - Data Acquisition

Req. F23	Analog Acquisition
Req. F24	Digital Acquisition

4.4.2 - Data Storage

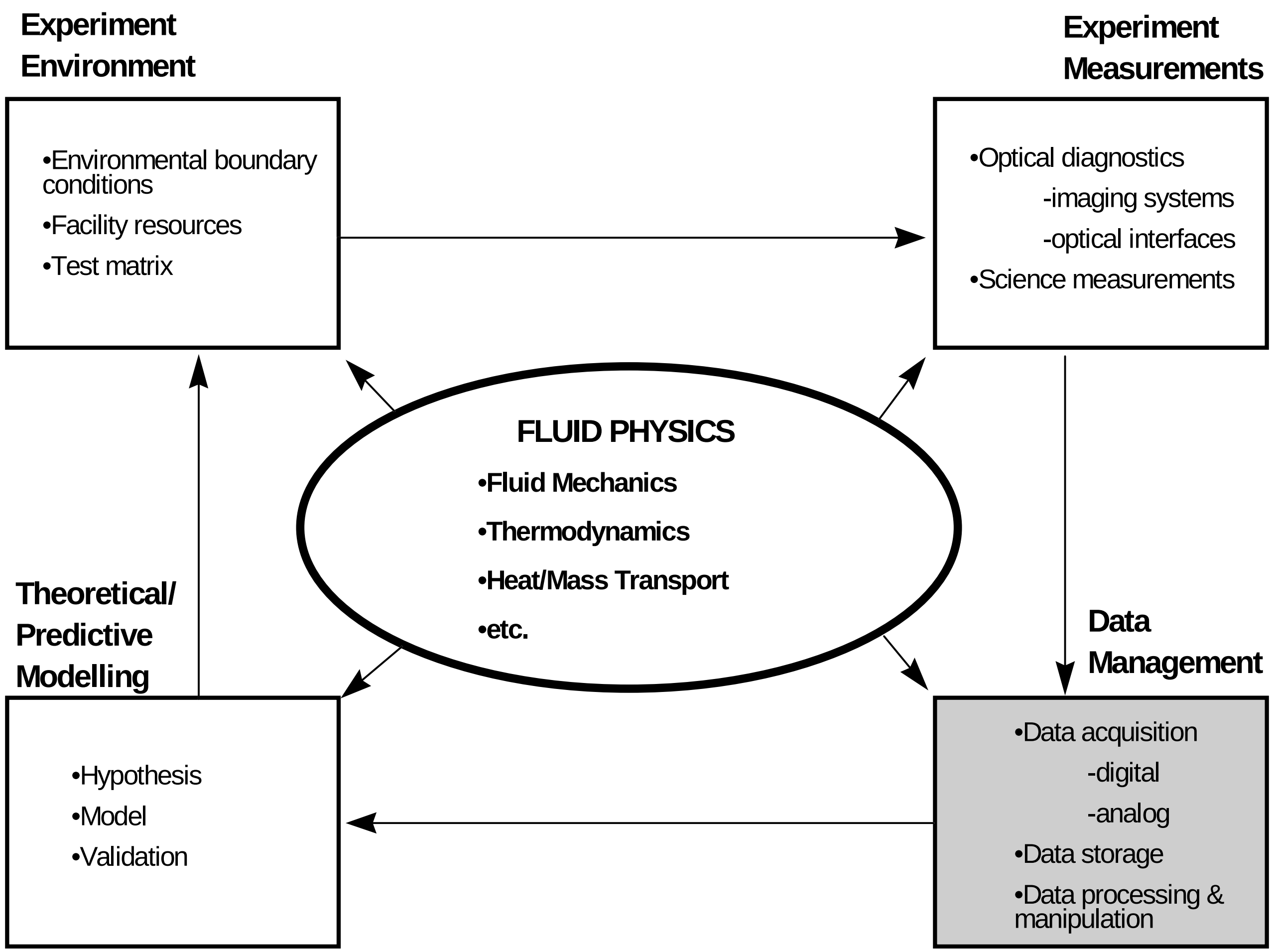
Req. F25	Data Recording
Req. F26	Data Time Tags

4.4.3 - Experiment Control

Req. F27	Analog Control
Req. F28	Internal/External Triggering
Req. F29	Digital Control
Req. F30	Experiment-Specific Capabilities

Facing figure illustrates the experimental process previously shown with the Data Management (this Section 4.4) highlighted. All requirements related to this process are in this section.

Experiment Process Model



4.4 EXPERIMENT DATA MANAGEMENT (cont.)

4.4.1 Data Acquisition

The facility shall supply an easily upgradable, flexible, modular, and "state-of-the-art" architecture for the acquiring, recording, retrieving, and transferring of data.

It is desired that the facility provide standard data acquisition and control systems that will easily interface with existing laboratory and commercial instrumentation.

Req. F23 - Analog Acquisition

The facility shall be capable of sampling up to 64 channels of analog signals (e.g., voltage, temperature, resistance, current, thermocouples, and so on.) to accommodate the ranges of signals and sampling rates required by the basis experiments. The system shall be capable of:

- a 16-bit A/D resolution (switchable to 8 bit), with signal integration capability, filtering, etc., providing an equivalent resolution of 8 1/2 digits.
- selectable sampling rates to 20 kHz with sample and hold capability for any single channel.
- adjustable gain
- monopolar or bipolar selection per channel, in order to take full advantage of the A/D dynamic range (e.g., ±1, ±2, ±5, ±10 Volts, similar for Ohms and Amps).
- single-ended and differential-ended types of measurement used simultaneously.

The facility should provide flexible capabilities for acquiring and digitizing multiple channels of analog data from each experiment. It is expected that the capability will be comparable to existing laboratory equipment and permit convenient upgrades as technology improves.

Des. F18

It is desired that the system be upgradable to 256 analog channels for future use.

4.4.1 Data Acquisition (cont.)

Req. F24 - Digital Acquisition

The facility shall provide at least 32 simultaneous TTL-level input channels.

The facility should provide flexible capabilities for acquiring multiple channels of digital data from each experiment.

A summary of data sampling rates required by the basis experiments is given below.

Sample Rates	*Experiments*
1 Hz	8, 11
10 Hz	1, 8, 11, 13b
100 Hz	3, 13a, 13b
>1000 Hz	13a

4.4.2 Data Storage

Req. F25 - Data Recording

The Fluid Facility shall provide

- at least 5 Gigabytes (expandable) of disk space for experiment-specific data
- at least 32 Mb of RAM (expandable) for the experiment specific control software

The facility must be capable of digitally recording all experiment-specific data as well as all experiment-related facility data for the duration of at least one experiment run. Such data storage must reliable retain data until it is analyzed or down-linked.

Des. DF19

It is desired that all data should be recorded using standard commercial formats that can be easily accessed by PI software.

4.4.2 Data Storage (cont.)

Req. F26 - Data Time Tags

The Fluids Facility shall provide the capability to time tag all data, including video data (Cf. Req. F15). This time tag shall be a standard reference to correlate all experiment and mission events.

All data should be correlated (within 1 second) to an external clock referenced by ISS systems (presumed to be GMT). All experiment data (analog, serial digital, and video, including facility "housekeeping data") should be correlated (within 0.01 second) and tagged for convenient time-based recovery and display. Experiment specific data streams will (potentially) be correlated to 0.001 second.

Correlation of multiple data streams over extended periods of operation will require careful management of the data. Tagging each data stream allow each investigator to correlate multiple experiment measurements with experiment-specific observations and external events.

Des. DF20

It is desired that the facility provide capability to tag data at selectable precision and frequency. The precision/resolution on time tagging should be consistent with the data sampling rate used.

4.4.3 Experiment Control

Req. F27 - Analog Control

The facility shall provide

- 16 channels of D/A (analog) outputs capable of arbitrary function generation as well as single voltage control.
- 16-bit D/A resolution at variable and flexible voltage ranges (monopolar as well as bipolar).

Des. DF21

It is desired that provisions be provided to increase the number of available D/A channels to 64 as demand increases.

Des. DF22

It is desired that a variety of wave forms be generated at selectable frequencies to 1 MHz and selectable amplitudes (typical function generator capabilities).

4.4.3 Experiment Control (cont.)

Req. F28 Internal/External Triggering

It is desired the facility shall provide internal and external triggering capability to enable the individual experiments to trigger and correlate the various events.

4.4.3 Experiment Control (cont.)

Req. F29 - Digital Control

The facility must provide digital control capabilities comparable to existing laboratory systems.

The facility shall provide at least 32 simultaneous TTL output channels.

4.4.3 Experiment Control (cont.)

Req. F30 - Experiment-Specific Capabilities

The facility must support experiment-specific hardware and electronic systems which are required to implement capabilities beyond the scope of the facility.

The facility shall be capable of accommodating experiment-specific software and hardware for experiment control and analysis. The facility shall provide a minimum of 2 slots for experiment specific electronic boards.

Des. DF23

It is desired that this capability accommodate any of the following experiment-specific plug-in boards. The recommended single board capabilities include:

- state-of-the-art frame grabber
- an oscilloscope board
- lock-in amplifier
- time correlator (which support both digital and analog inputs)
- strain-gauge measurement
- thermocouple reference and amplifier
- frequency synthesizer

Des. DF24

It is desired that the custom electronics enclosure provide accommodations for high-quality, low-noise measurement capabilities which may require careful protection from electromagnetic interference and temperature variations.